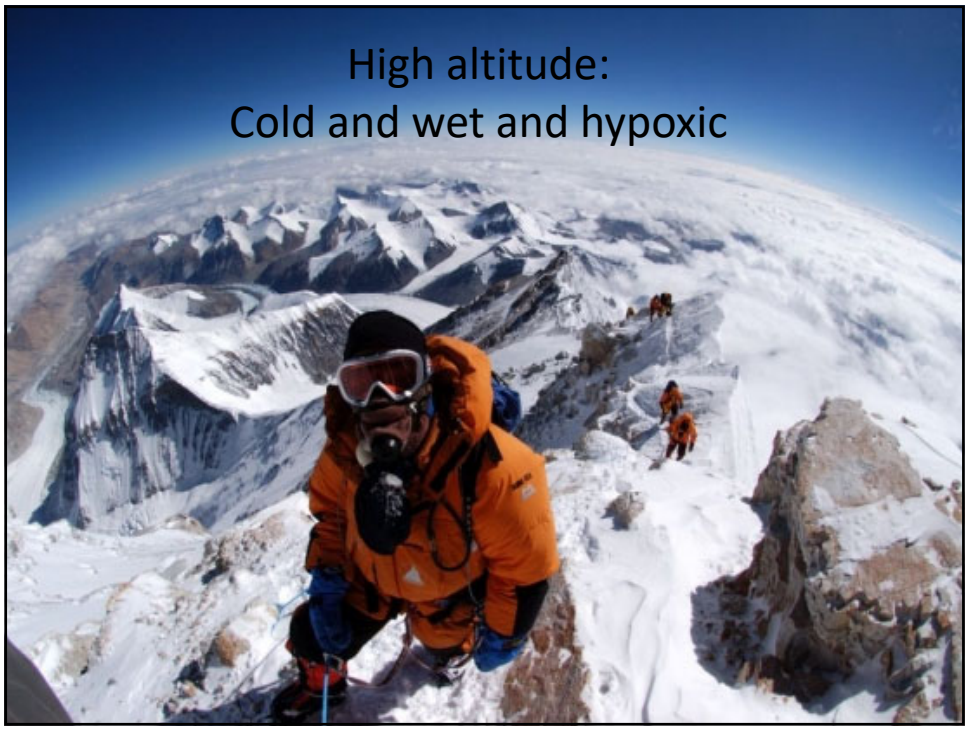
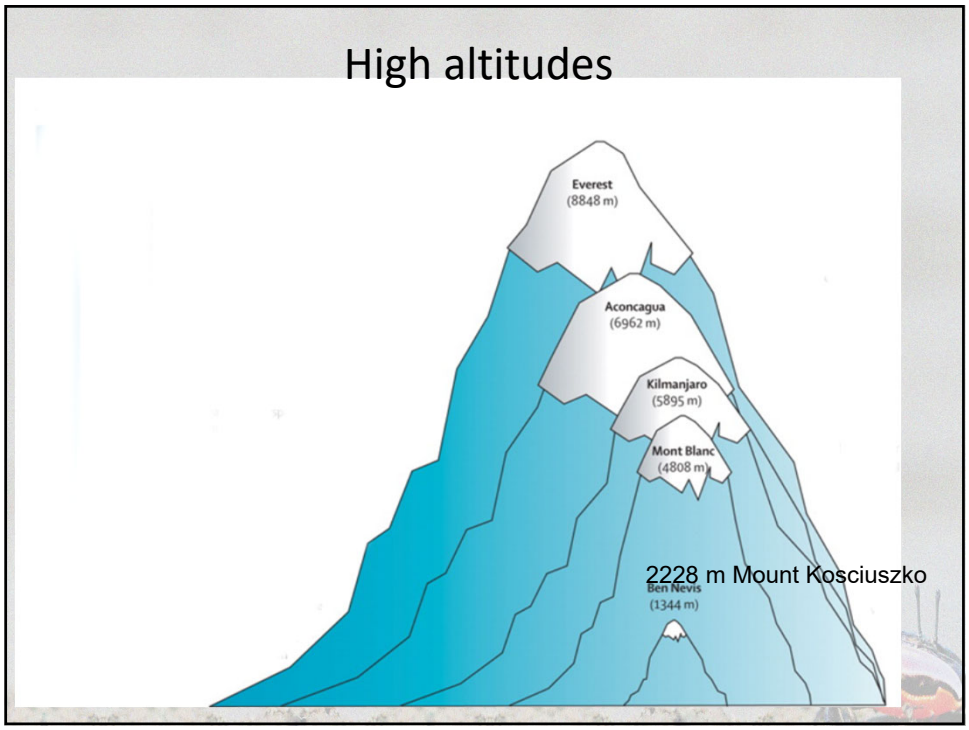

High altitude:
Cold and wet and hypoxic

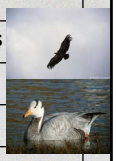
1


High altitudes
Everest
(8848 m)
Aconcagua
(6962 m)
Kilmanjaro
(5895 m)
Mont Blanc
(4808 m)
Ben Nevis
(1344 m)
2228 m Mount Kosciuszko

2

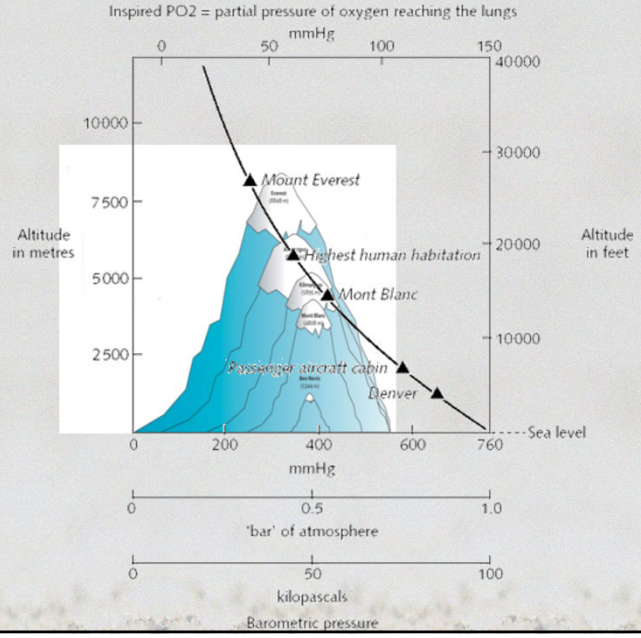
# Animals at altitude

| Altitude/Depth | Air Pressure (kPa) | $pO_2$ (kPa) | |
|---|---|---|---|
| >20000 m | < 6 | < 1 | Water boils at 20°C |
| 20000 m | 6 | 1 | Only water vapour in lungs |
| 12300 m | 20 | 4 | Pure $O_2$ "ceiling" |
| 8800 m | 34 | 7 | Mt Everest |
| 6200 m | 56 | 12 | Normal $O_2$ "ceiling" |
| 2230 m | 80 | 16 | Mt Kosciuzko |
| 0 m | 101 | 21 | Sea level |
| -10 m | 202 | 42 | 101 kPa/10 m water depth |
| -40 m | 505 | 105 | Bends, chronic $O_2$ toxicity |
| -80 m | 909 | 189 | $N_2$ narcosis |
| -190 m | 2020 | 420 | Acute $O_2$ toxicity |



3

# Altitude hypoxia




4

# Humans conquering everest

Hillary/Norgay 1953

Edmund Hillary

New Zealand mountaineer

Sir Edmund Percival Hillary KG ONZ KBE was a New Zealand mountaineer, explorer, and philanthropist. On 29 May 1953, Hillary and Sherpa mountaineer Tenzing Norgay became the first climbers confirmed to have reached the summit of Mount Everest. They were part of the ninth British expedition to Everest, led by John Hunt.

Messner/Habeler 1978

Reinhold Messner

On 8 May 1978, Reinhold Messner and Peter Habeler reached the **summit** of **Mount Everest**; the **first** men known to **climb** it **without** the use of supplemental **oxygen**. Prior to this **ascent** it was disputed whether this was possible at all.

5

# Animals at altitude: how high?

TABLE 13–12

Summary of the altitudinal limits for a variety of animals. *(Adapted from Bouverot 1985.)*

| | Altitude (km) | Geographic Locality |
|---|---|---|
| **Amphibians** | | |
| *Salamandra* | 3 | European Alps |
| *Telmatobius* | 3.8 | Lake Titicaca, Peru |
| *Eleutherodactylus* | 4.5 | Andes, Peru |
| *Bufo* | 5 | Himalaya |
| **Fish** | | |
| Trout | 2.8 | European Alps |
| Trout | 3.8 | Lake Titicaca, Peru |
| *Nemachilus* | 4.7 | Asia |
| **Reptiles** | | |
| Scleroporine lizard | 3.4 | SW USA |
| African skink | 4 | Kilimanjaro, Tanzania |
| Iguanid lizards | 4.9 | Andes, Peru |
| Lizards | 5.5 | Himalaya |
| **Birds** | | |
| Domestic fowl | 4 | |
| Various families | 4–6.5 | Rocky Mountains, USA and Andes, Peru |
| Lammergeier | 5–6 | Himalaya |
| Barheaded goose | >8.8 | Himalaya |
| **Mammals** | | |
| Deer mice | 4 | Rocky Mountains, USA |
| Human habitations | >4.5 | Andes, Peru and Himalaya |
| Llama, guanaco, alpaca | 4.8–5.4 | Andes, Peru |
| Chinchilla | 5 | Andes, Peru |
| Yak | 5.8 | Asia |
| Taruca (deer) | 6 | Andes, Peru |
| Humans without pure $O_2$ | 8.8 | Mt. Everest, Himalaya |

6

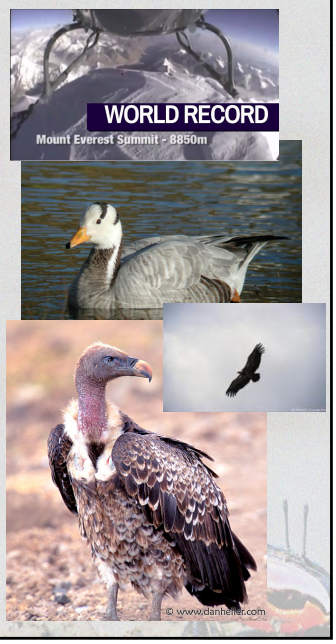
# High-flying birds

At 8848 m, Mount Everest has only a third of the oxygen available at sea level

- you lose consciousness within minutes
- kerosene cannot burn
- helicopters (most) cannot fly.

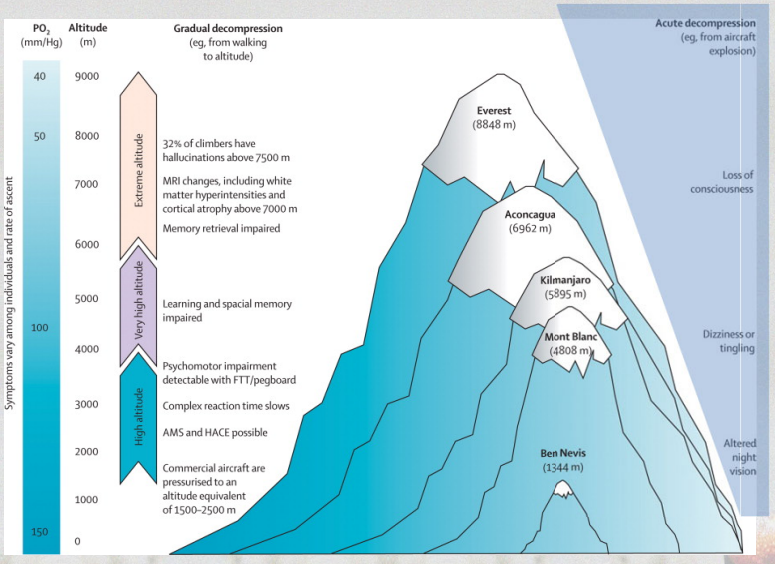
Bar-headed geese can fly over Mt Everest

The highest-flying bird ever recorded was a Ruppell's griffon vulture (wingspan about 3 meters) @ 12,200m




7

# Effects of high altitude




8

# Human hypoxia

| Altitude (m) | Atmospheric pressure (kPa) | Ambient $P_{O_2}$ (kPa) | Alveolar $P_{O_2}$ (kPa) | Alveolar $P_{CO_2}$ (kPa) |
|---|---|---|---|---|
| 0 | 101 | 21.1 | 13.8 | 5.3 |
| 3 100 | 71 | 14.6 | 8.9 | 4.8 |
| 4 340 | 62 | 12.8 | 6.0 | – |
| 5 300 | | Ceiling for unacclimated humans | | |
| 5 500 | | Highest human habitation | | |
| 6 200 | 46 | 9.7 | 5.3 | 3.2 |
| 6 000–7 000 | | Ceiling for acclimated humans | | |
| 8 500 | | Human breathing possible for a few hours | | |
| 8 848 | 33 | 6.9 | 4.0 | 1.5 |
| 9 200 | 30 | 6.3 | 2.8 | – |
| 12 300 | 19 | 3.9 | 1.1 | – |
| 14 460 | | Ceiling for humans with pure oxygen supply | | |
| 15 400 | 12 | 2.4 | 0.1 | ~0 |
| 20 000 | 6 | 1.3 | 0 | 0 |

Mt Everest

**760 mmHg = 101 kPa**

9

# Human hypoxia

| Altitude (m) | Atmospheric pressure (kPa) | Ambient $P_{O_2}$ (kPa) | Alveolar $P_{O_2}$ (kPa) | Alveolar $P_{CO_2}$ (kPa) |
|---|---|---|---|---|
| 0 | 101 | 21.1 | 13.8 | 5.3 |
| 3 100 | 71 | 14.6 | 8.9 | 4.8 |
| 4 340 | 62 | 12.8 | 6.0 | – |
| 5 300 | | Ceiling for unacclimated humans | | |
| 5 500 | | Highest human habitation | | |
| 6 200 | 46 | 9.7 | 5.3 | 3.2 |
| 6 000–7 000 | | Ceiling for acclimated humans | | |
| 8 500 | | Human breathing possible for a few hours | | |
| 8 848 | 33 | 6.9 | 4.0 | 1.5 |
| 9 200 | 30 | 6.3 | 2.8 | – |
| 12 300 | 19 | 3.9 | 1.1 | – |
| 14 460 | | Ceiling for humans with pure oxygen supply | | |
| 15 400 | 12 | 2.4 | 0.1 | ~0 |
| 20 000 | 6 | 1.3 | 0 | 0 |

Mt Everest

**760 mmHg = 101 kPa**

10

# Human hypoxia

| Altitude (m) | Atmospheric pressure (kPa) | Ambient $P_{O_2}$ (kPa) | Alveolar $P_{O_2}$ (kPa) | Alveolar $P_{CO_2}$ (kPa) |
|---|---|---|---|---|
| 0 | 101 | 21.1 | 13.8 | 5.3 |
| 3 100 | 71 | 14.6 | 8.9 | 4.8 |
| 4 340 | 62 | 12.8 | 6.0 | – |
| 5 300 | | Ceiling for unacclimated humans | | |
| 5 500 | | Highest human habitation | | |
| 6 200 | 46 | 9.7 | 5.3 | 3.2 |
| 6 000–7 000 | | Ceiling for acclimated humans | | |
| 8 500 | | Human breathing possible for a few hours | | |
| 8 848 | 33 | 6.9 | 4.0 | 1.5 |
| 9 200 | 30 | 6.3 | 2.8 | – |
| 12 300 | 19 | 3.9 | 1.1 | – |
| 14 460 | | Ceiling for humans with pure oxygen supply | | |
| 15 400 | 12 | 2.4 | 0.1 | ~0 |
| 20 000 | 6 | 1.3 | 0 | 0 |

Mt Everest

**760 mmHg = 101 kPa**

11

# Human hypoxia

| Altitude (m) | Atmospheric pressure (kPa) | Ambient $P_{O_2}$ (kPa) | Alveolar $P_{O_2}$ (kPa) | Alveolar $P_{CO_2}$ (kPa) |
|---|---|---|---|---|
| 0 | 101 | 21.1 | 13.8 | 5.3 |
| 3 100 | 71 | 14.6 | 8.9 | 4.8 |
| 4 340 | 62 | 12.8 | 6.0 | – |
| 5 300 | | Ceiling for unacclimated humans | | |
| 5 500 | | Highest human habitation | | |
| 6 200 | 46 | 9.7 | 5.3 | 3.2 |
| 6 000–7 000 | | Ceiling for acclimated humans | | |
| 8 500 | | Human breathing possible for a few hours | | |
| 8 848 | 33 | 6.9 | 4.0 | 1.5 |
| 9 200 | 30 | 6.3 | 2.8 | – |
| 12 300 | 19 | 3.9 | 1.1 | – |
| 14 460 | | Ceiling for humans with pure oxygen supply | | |
| 15 400 | 12 | 2.4 | 0.1 | ~0 |
| 20 000 | 6 | 1.3 | 0 | 0 |

Mt Everest

Acid-base

**760 mmHg = 101 kPa**

12

# Effects of high altitude

Acute time of useful consciousness

| Altitude | Time of Useful Consciousness |
|---|---|
| 45,000 feet MSL | 9 to 15 seconds |
| 40,000 feet MSL | 15 to 20 seconds |
| 35,000 feet MSL | 30 to 60 seconds |
| 30,000 feet MSL | 1 to 2 minutes |
| 28,000 feet MSL | 2 1/2 to 3 minutes |
| 25,000 feet MSL | 3 to 5 minutes |
| 22,000 feet MSL | 5 to 10 minutes |
| 20,000 feet MSL | 30 minutes or more |

Mt Everest

13

# Altitude hypoxia barometric pressure

| Altitude (ft) | Barometric Pressure (mm Hg) | $P_{O_2}$ in Air (mm Hg) | Breathing Air: $P_{CO_2}$ in Alveoli (mm Hg) | Breathing Air: $P_{O_2}$ in Alveoli (mm Hg) | Breathing Air: Arterial Oxygen Saturation (%) | Breathing Pure Oxygen: $P_{CO_2}$ in Alveoli (mm Hg) | Breathing Pure Oxygen: $P_{O_2}$ in Alveoli (mm Hg) | Breathing Pure Oxygen: Arterial Oxygen Saturation (%) |
|---|---|---|---|---|---|---|---|---|
| 0 | 760 | 159 | 40 | 104 | 97 | 40 | 673 | 100 |
| 10,000 | 523 | 110 | 36 | 67 | 90 | 40 | 436 | 100 |
| 20,000 | 349 | 73 | 24 | 40 | 73 | 40 | 262 | 100 |
| 30,000 | 226 | 47 | 24 | 21 | 30 | 40 | 139 | 99 |
| 40,000 | 141 | 29 | 24 | 12 | 15 | 36 | 58 | 87 |
| 50,000 | 87 | 18 | 24 | 2 | 2 | 24 | 16 | 22 |

14

# Altitude hypoxia
# partial oxygen

Consequently, air pO2 declines with altitude:

| | | | Breathing Air | | | Breathing Pure Oxygen | | |
|---|---|---|---|---|---|---|---|---|
| Altitude (ft) | Barometric Pressure (mm Hg) | $P_{O_2}$ in Air (mm Hg) | $P_{CO_2}$ in Alveoli (mm Hg) | $P_{O_2}$ in Alveoli (mm Hg) | Arterial Oxygen Saturation (%) | $P_{CO_2}$ in Alveoli (mm Hg) | $P_{O_2}$ in Alveoli (mm Hg) | Arterial Oxygen Saturation (%) |
| 0 | 760 | 159 | 40 | 104 | 97 | 40 | 673 | 100 |
| 10,000 | 523 | 110 | 36 | 67 | 90 | 40 | 436 | 100 |
| 20,000 | 349 | 73 | 24 | 40 | 73 | 40 | 262 | 100 |
| 30,000 | 226 | 47 | 24 | 21 | 30 | 40 | 139 | 99 |
| 40,000 | 141 | 29 | 24 | 12 | 15 | 36 | 58 | 87 |
| 50,000 | 87 | 18 | 24 | 2 | 2 | 24 | 16 | 22 |

(pO2 is ~ 7 kPa or 45 torr on Mt Everest)

15

# Altitude hypoxia

Breathing air works to about 24'000 feet when blood $O_2$ saturation declines to < 50%

| | | | Breathing Air | | | Breathing Pure Oxygen | | |
|---|---|---|---|---|---|---|---|---|
| Altitude (ft) | Barometric Pressure (mm Hg) | $P_{O_2}$ in Air (mm Hg) | $P_{CO_2}$ in Alveoli (mm Hg) | $P_{O_2}$ in Alveoli (mm Hg) | Arterial Oxygen Saturation (%) | $P_{CO_2}$ in Alveoli (mm Hg) | $P_{O_2}$ in Alveoli (mm Hg) | Arterial Oxygen Saturation (%) |
| 0 | 760 | 159 | 40 | 104 | 97 | 40 | 673 | 100 |
| 10,000 | 523 | 110 | 36 | 67 | 90 | 40 | 436 | 100 |
| 20,000 | 349 | 73 | 24 | 40 | 73 | 40 | 262 | 100 |
| 30,000 | 226 | 47 | 24 | 21 | 30 | 40 | 139 | 99 |
| 40,000 | 141 | 29 | 24 | 12 | 15 | 36 | 58 | 87 |
| 50,000 | 87 | 18 | 24 | 2 | 2 | 24 | 16 | 22 |

"normal ceiling" is about 24000 feet

16

# Altitude hypoxia

Breathing pure O2 works to about 46000 feet when blood O2 saturation declines to < 50%:

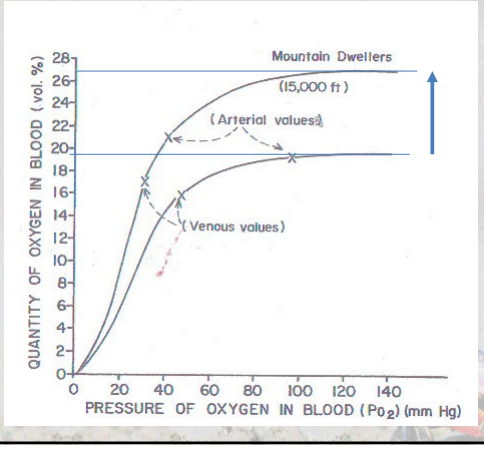
| | | | Breathing Air | | | Breathing Pure Oxygen | | |
|---|---|---|---|---|---|---|---|---|
| Altitude (ft) | Barometric Pressure (mm Hg) | $P_{O_2}$ in Air (mm Hg) | $P_{CO_2}$ in Alveoli (mm Hg) | $P_{O_2}$ in Alveoli (mm Hg) | Arterial Oxygen Saturation (%) | $P_{CO_2}$ in Alveoli (mm Hg) | $P_{O_2}$ in Alveoli (mm Hg) | Arterial Oxygen Saturation (%) |
| 0 | 760 | 159 | 40 | 104 | 97 | 40 | 673 | 100 |
| 10,000 | 523 | 110 | 36 | 67 | 90 | 40 | 436 | 100 |
| 20,000 | 349 | 73 | 24 | 40 | 73 | 40 | 262 | 100 |
| 30,000 | 226 | 47 | 24 | 21 | 30 | 40 | 139 | 99 |
| 40,000 | 141 | 29 | 24 | 12 | 15 | 36 | 58 | 87 |
| 50,000 | 87 | 18 | 24 | 2 | 2 | 24 | 16 | 22 |

"pure $O_2$ ceiling" is about 46000 feet

17

# Adaptations to altitude (1)

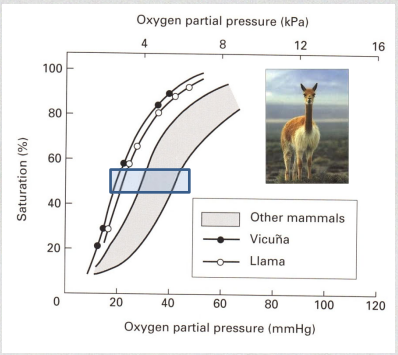
An increase in blood haemoglobin (which increases the blood $O_2$ carrying capacity)

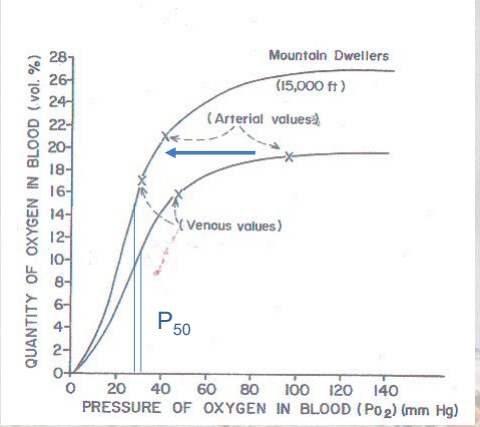



18

# Adaptations to altitude (2)

Changes in blood organophosphates (DPG) to shift the $O_2$ dissociation curve to the left



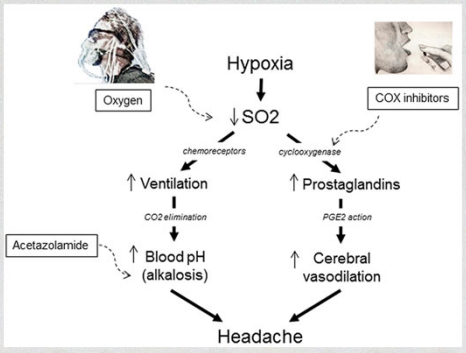

19

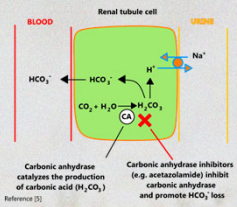
# Adaptations to altitude (3)

Higher lung volume

But, hyperventilation doesn't. this fails to maintain a high alveolar/arterial $pO_2$ and "blows off" $CO_2$.

Oxygen, Acetazolamide and COX inhibitors (ibuprofen)




20

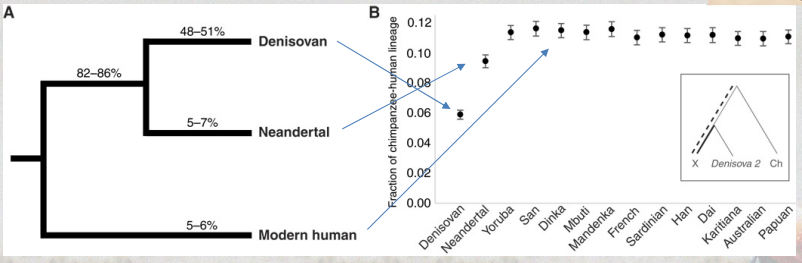
# Denisovans

So who were the Denisovans?!

Archaic hominin lineage

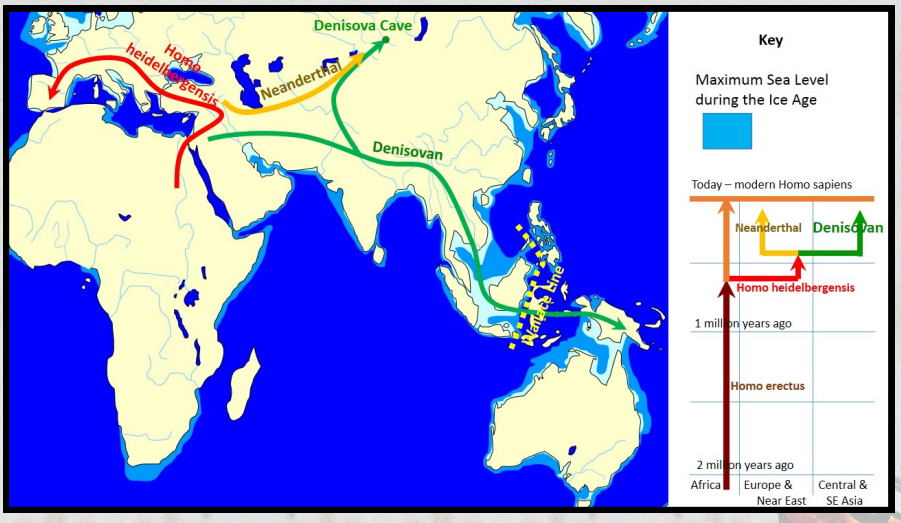
Sister group to Neanderthals

Once common in Asia (at altitude –
the abominable snowman aka "Yeti"?!).




21

# Denisovans



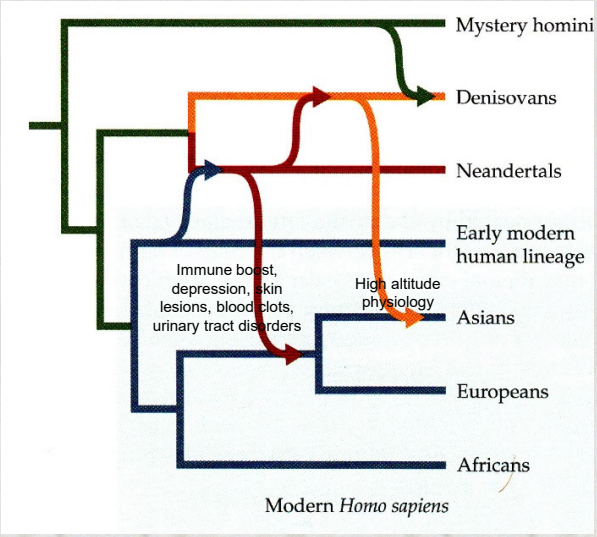

22

# Denisovan genes in humans?!

Presence of Denisovan genes in Tibetans suggests that admixture of human with other hominin genes provides genetic variation (EPAS1) favourable for particular environments e.g. altitude hypoxia

23

# Homo sapiens hybridisation is not unusual!




24